SHRUB BURIAL BY SNOW DEPOSITION IN IMMATURE COASTAL FORESTS:

A Review and Recommendations

INTEGRATED WILDLIFE INTENSIVE FORESTRY RESEARCH

BC

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SHRUB BURIAL BY SNOW DEPOSITION IN IMMATURE COASTAL FORESTS: A Review and Recommendations

by

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1 INTRODUCTION

Snowfall can restrict Columbian black-tailed deer (*Odocoileus hemionus columbianus* Richardson) use of winter habitat, in part by burying understory forage (Harestad *et al.* 1982; Bunnell and Jones 1984; Nyberg *et al.* 1986). Simulation models evaluating the tradeoffs between factors affecting energetics of mule deer (*O. h. hemionus*) or Columbian black-tailed deer during winter (e.g., thermoregulation, reproduction, fat store catabolism, snow locomotion, forage intake) have identified the process of forage burial by snow as the dominant factor controlling deer energy status (Wickstrom *et al.* 1984; Jay 1985; Hovey and Kremsater[1]). In the past, forage abundance in the presence of snow has been estimated by integrating some function that uses the difference between total snow depth or mean snow depth and the pre-winter plant height distribution (Jones 1974, 1975; Harestad 1979; Rochelle 1980; Moen 1981; Potvin and Huot 1983). The important assumption underlying this methodology is that snow deposition does not affect plant height above the ground. Several observations of forage plants buried by snow much less than their height (Jones 1975; Harestad 1979; Rochelle 1980; Schwab 1985; Schwab and Pitt [in press]; Schwab *et al.* [in press]) suggest that this assumption is incorrect. Forage plants exhibit flexibility; they are often displaced downwards by snowfalls and by changes in the depth and composition of the snowpack (Harestad and Bunnell 1984; Gauld 1985; Schwab and Pitt [in press]; Schwab *et al.* [in press]). Hence, during winters that have snowfalls, understory plants seldom remain vertically stationary. Because they can intercept snow, important black-tailed deer forage species such as huckleberry (*Vaccinium* spp.) and salal (*Gaultheria shallon*) (Harestad 1979; Rochelle 1980; Bunnell and Jones 1984) are vulnerable to the process of displacement by snow. When intercepted snow accumulates on a plant's crown, the additional weight can cause it to bend downwards. This displacement makes the plant more susceptible to further displacement because it allows snow to accumulate along the plant's stem (Harestad and Bunnell 1984). Given this process of positive feedback, a plant can eventually become completely buried by snow depths much less than its original height. Once snow has melted from their crowns and stems, plants do not always resume their pre-winter height; ice and snow at the base of the stems can prevent them from returning to their original positions. Schwab and Pitt [in press], for example, reported browse exceeding 0.5 m in height

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[1]Hovey, F.W., and L.L. Kremsater. [1987]. A simulation model of black-tailed deer energetics and habitat selection during winter. Univ. B.C. In preparation.

trapped beneath snow and ice only 1 cm deep. This restriction of upward movement imposed by snow and ice can leave forage plants even more susceptible to the burial processes of subsequent snowstorms.

The implications of snow burial processes are important to the management of ungulate winter range. Because forage plants can be buried by snow much less than their height, winter carrying capacity, for example, can be seriously overestimated if based on the assumption that plants are not displaced by snow. If this assumption is used, Schwab and Pitt [in press] calculated that moose carrying capacity would be overestimated by 36%. Because black-tailed deer winter forage is typically much more flexible than moose winter forage, the overestimate for black-tailed deer winter ranges may be even larger.

2 A REVIEW

Despite its predominant importance, the process of shrub burial by snow and the factors that affect it have received little research relative to other components of deer energetics (e.g., thermoregulation, locomotion). On the southern coast of British Columbia, four studies have attempted to examine displacement and burial dynamics of salal and huckleberry by snow: Harestad and Bunnell (1984), Gauld (1985), F.W. Hovey and A. Rahme (unpublished data, 1985/86, Univ. of B.C., Vancouver, B.C.), and C. van der Mark[2]. Primarily, these studies have had three objectives:

1. to document the downward, vertical displacement of salal and huckleberry plants by snow;

2. to develop regression equations relating the amount of plant remaining above snow to snow depth and original plant height; and

3. to quantify the effects of snow depth and original plant height on the probability of plant burial.

The following represents a brief review of the location, methods, and results of these studies.

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[2]Carl van der Mark is a University of B.C. Forestry student who worked on salal and huckleberry burial for his B.S.F. thesis during the 1985/86 winter. He has not yet completed his thesis; consequently, none of his results are currently available.

2.1 Study Areas

The Harestad and Bunnell (1984) and van der Mark (unpubl.) studies occurred in Mt. Seymour Provincial Park, near North Vancouver; Gauld (1985) and Hovey and Rahme (unpubl. data) located their projects within ≃200 m. of each other in Mt. Cypress Provincial Park, near West Vancouver. All of these studies occurred on southern aspects at similar elevations (760 m and 460 m; 840 m and 540 m; 720 m and 550 m; 715 m and 550 m, respectively) in the Coastal Western Hemlock Biogeoclimatic Zone, within 60- to 80-year-old, immature forests. These forests were dominated by western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*), with Douglas-fir (*Pseudotsuga menziesii*) and red alder (*Alnus rubra*) occurring sporadically. Depending on elevation, salal or huckleberry dominated the understory. Each study treated salal and huckleberry at different locations. In each case, the salal site occurred at a lower elevation. The low elevations, southern aspects, and understory vegetation of the various study areas match some of the characteristics that define black-tailed deer winter range (see Nyberg *et al.* 1986).

2.2 Methods

With only a few modifications, all studies followed the methods of Harestad and Bunnell (1984). At both the salal and huckleberry sites, 100 plants were chosen in groups of five. Each group constituted a plot varying in area from ≃10 to 20 m^2. The variable plot size was due to the criterion of selecting plants covering as broad a range in height as possible. As a result of this criterion, the height distribution of selected plants is not representative of the height distribution of the plant population (Fig. 1). This intentional sampling bias is justified because one of the aims of these studies was to assess the effect of plant height on the amount of vertical displacement and the probability of plant burial given a particular snow depth. Consequently, plant height was treated as an independent factor, and thus, a broad range of heights was necessary to ensure proper estimation of its effect. At each site, the 20 plots of five plants were located along a ≃250-m transect set parallel to the contour of the terrain. Because understory vegetation was contagiously distributed, plots were not equispaced along the transect; instead, they were opportunistically located whenever shrubs occurred in sufficient density ≃10-15 m from the previous plot. Each plant was first tagged near its top with numbered flagging tape and then the plant's total and tag height above the ground was measured with a

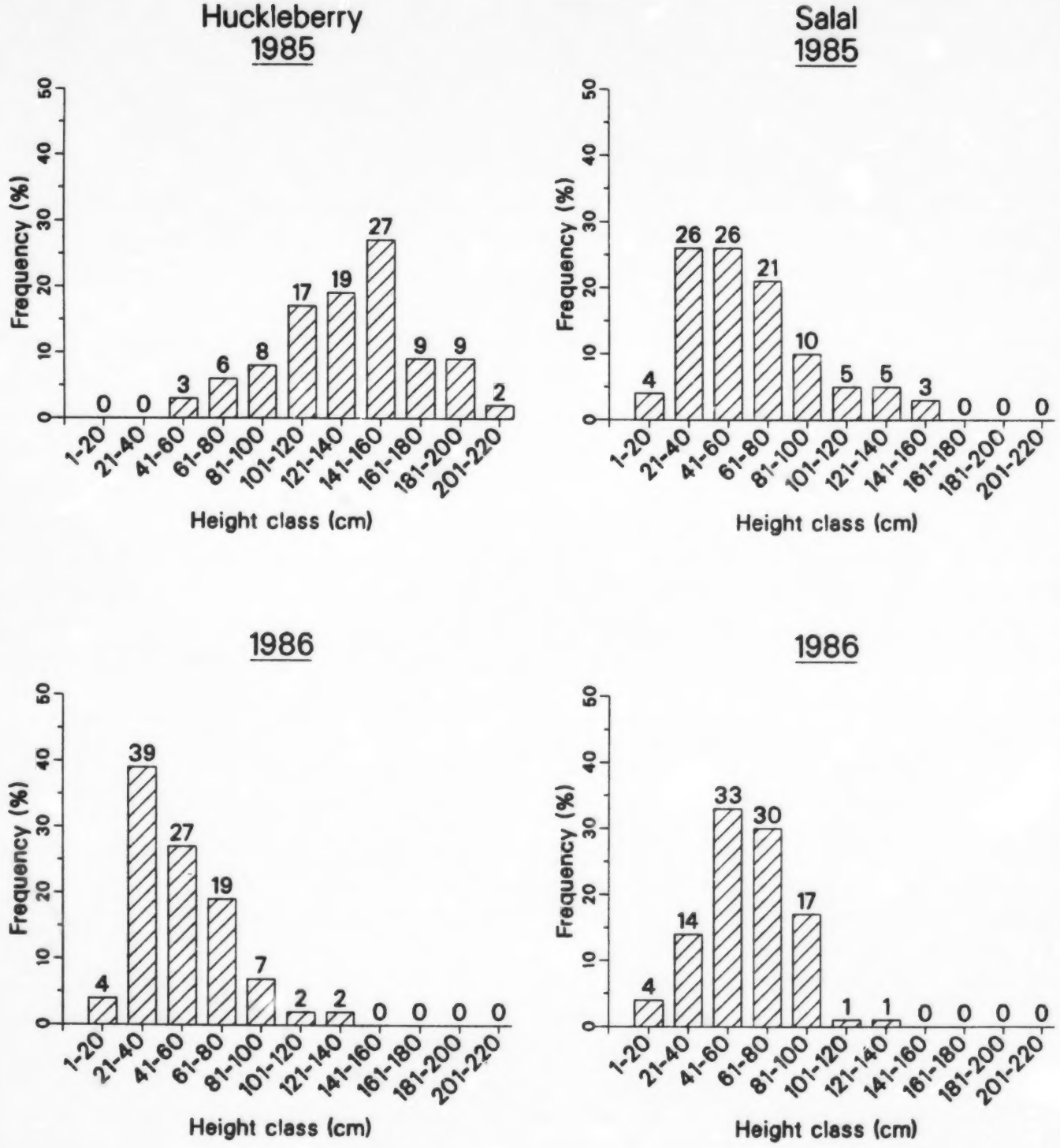

Figure 1. Pre-winter tag height distribution of huckleberry (*Vaccinium* spp.) and salal (*Gaultheria shallon*) plants for 1984/85 (data from Gauld 1985) and 1985/86 winters, respectively.

meter stick held perpendicular to the horizontal plane. Following snowfalls exceeding 5 cm in depth in the open, the snow depth at the plant and the tag height above the surface of the snowpack was measured. If the tag was not visible the plant was recorded as buried. In these cases, a snow depth was taken in the plot and assigned to the buried plant. To facilitate the location of buried plants, and thus provide accurate snow depth measurements, Hovey and Rahme (unpubl. data) placed bamboo stakes (2 cm diameter, 1.5 m length) upslope from each plant. These stakes later proved useful in locating plants that had lost tags. To improve the precision of estimates of mean snow depth, within each plot Hovey and Rahme (unpubl. data) also recorded five additional, randomly located snow depth measurements. Gauld (1985) followed the procedures outlined by Harestad and Bunnell (1984), except he also sampled his sites on an approximately weekly basis to monitor changes in the snowpack and he did not record snow depths for buried plants. Occasionally (10 times at the salal site and 20 times at the huckleberry site), he found all of the plants in a plot buried; consequently, no snow depths were recorded and none can be estimated for those plots. As a result, appropriate analysis of his data is not possible.

2.3 Results

The winters in which Harestad and Bunnell (1984) and Hovey and Rahme (unpubl. data) conducted their research were mild; in each case, only three adequate snowfalls occurred. Harestad and Bunnell's salal site did not receive snow. The mean snow depths (averaged over plots) at their huckleberry site ranged from 23.4 ± 1.1 (SE) cm to 35.7 ± 1.0 cm (Tables 1 and 2). Hovey and Rahme (unpubl. data) recorded mean snow depths ranging from 12.5 ± 0.6 cm to 28.8 ± 0.6 cm and 1.1 ± 0.03 to 19.1 ± 0.3 cm for salal and huckleberry, respectively.[3] The winter of 1984/85, during which Gauld (1985) conducted his research, had greater and more frequent snowfalls on the huckleberry site than did the previous and following winters (Tables 1 and 2). Gauld (1985) recorded four snowfalls on his salal site and seven snowfalls on his huckleberry site, with snow depths ranging from 0.3 ± 0.2 cm to 15.8 ± 2.4 cm and 41.6 ± 2.0 cm to 77.1 ± 5.4 cm, respectively. Because Gauld's procedure did not include measuring snow depths at buried plants, these means may

[3]Despite its higher elevation, the huckleberry site had lower snow depths than did the salal site. This result may be attributable to the huckleberry site's greater canopy closure (visual estimate) and thus greater snow interception efficiency.

Table 1. Snow depths and number of plants buried at huckleberry (*Vaccinium* spp.) sites

	Sample date	n	Snow depth (cm) mean ± SE	Minimum	Maximum	Number buried
Harestad and Bunnell (1984)	Dec 30	100	35.7 1.0	19	58	47
	Feb 15	100	23.4 1.1	2	60	44
	Feb 21	100	25.3 1.3	0	70	50
Gauld (1985)	Jan 10	56	66.9 21.8	0	126	42
	Jan 18	61	58.4 17.7	0	118	36
	Jan 22	70	46.2 17.6	0	106	26
	Jan 28	70	41.6 16.4	0	90	25
	Feb 01	68	53.3 18.7	0	105	27
	Feb 08	55	64.6 18.2	20	132	39
	Feb 15	38	75.7 15.7	21	122	56
	Mar 03	28	77.1 28.5	4	137	65
	Mar 13	27	70.9 27.4	5	119	66
	Mar 20	32	54.3 26.0	0	95	60
Hovey and Rahme (unpubl. data)	Dec 30	200	1.1 0.04	0	3	0
	Feb 16	200	19.1 0.35	6	35	9
	Feb 18	200	19.0 0.69	6	141	11

Table 2. Snow depths and number of plants buried at salal (*Gaultheria shallon*) sites

	Sample date	n	Snow depth (cm) mean ± SE	Minimum	Maximum	Number buried
Gauld (1985)	Jan 07	46	3.4 3.1	0	14	34
	Jan 18	75	0.0 0.0	0	0	0
	Jan 28	78	0.0 0.0	0	0	0
	Feb 01	78	1.0 0.0	1	1	0
	Feb 08	33	14.8 1.7	10	21	45
	Feb 15	13	15.8 1.5	9	23	64
	Mar 13	66	0.3 1.5	0	8	10
	Mar 20	74	0.0 0.0	0	0	0
Hovey and Rahme (unpubl. data)	Jan 02	200	12.5 0.6	1	43	32
	Feb 16	200	28.8 0.6	2	56	39
	Feb 18	200	27.1 0.5	11	55	44

be biased underestimates of the actual means. Unlike the winter that followed it, the 1984/85 winter's snowpack at the huckleberry site did not completely melt between snow events.

Each of the studies reported vertical displacement of plants by snow. Figure 2 illustrates the amount of displacement for the 1985 and 1986 studies[4]. For each case, restricted regressions (i.e., intercept = 0) of measured tag height following snow as a function of original tag height produced slopes (b_1=0.86, SE=0.01 [huckleberry 1985]; 0.74, 0.01 [salal 1985]; 0.91, 0.001 [huckleberry 1986]; 0.63, 0.012 [salal 1986]) significantly less than 1.0 (t-test, $P \leq 0.01$). This significant departure from 1.0 indicates that downward displacement of plants by snow had occurred. For huckleberry, Harestad and Bunnell (1984) reported a similar regression resulting in a significant slope of 0.75 ($P \leq .01$). They also reported between 23 and 35% of the huckleberry plants studied were buried by snow depths less than plant height. Gauld (1985) found that 25-75% of the huckleberry and 16-86% of the salal plants were buried by snow depths less than plant height. Using the same comparisons, Hovey and Rahme (unpubl. data) reported that less than 1% of huckleberry plants and 25-75% of salal plants were buried. Figure 3 shows the average percentage (averaged over sampling dates) of plants buried by snow less than plant height for each of the studies[5]. In general, the figure shows that tall plants were less vulnerable to burial than were short ones. Specifically, the curves for the salal plants exhibited a peaked relationship. That is, salal plants 40-60 cm in height were more susceptible to burial than were plants either taller or smaller than that height class. This result may be due to changes in the plant's growth form and flexibility as a function of age and height. Snow depth also affects the proportion of plants buried (Tables 3-6). The interaction of snow depth and plant height on the proportion of plants buried and the amount of plant available as forage is complicated; consider-

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[4]Some of these graphs (e.g., huckleberry 1985) show points above the 1:1 line, indicating that plants had become taller in the presence of snow. This counter-intuitive result was also reported by Harestad and Bunnell (1984). They attributed it to downward and lateral displacement of plants over uneven or sloping ground. Given the method of tag height measurement, if the snowpack surface directly below the tag was lower than the base of the plant's stem, then the measured tag height could be higher than the original tag height, thus producing the noted results.

[5]The figure only shows those study sites where data were extensive enough to produce graphs.

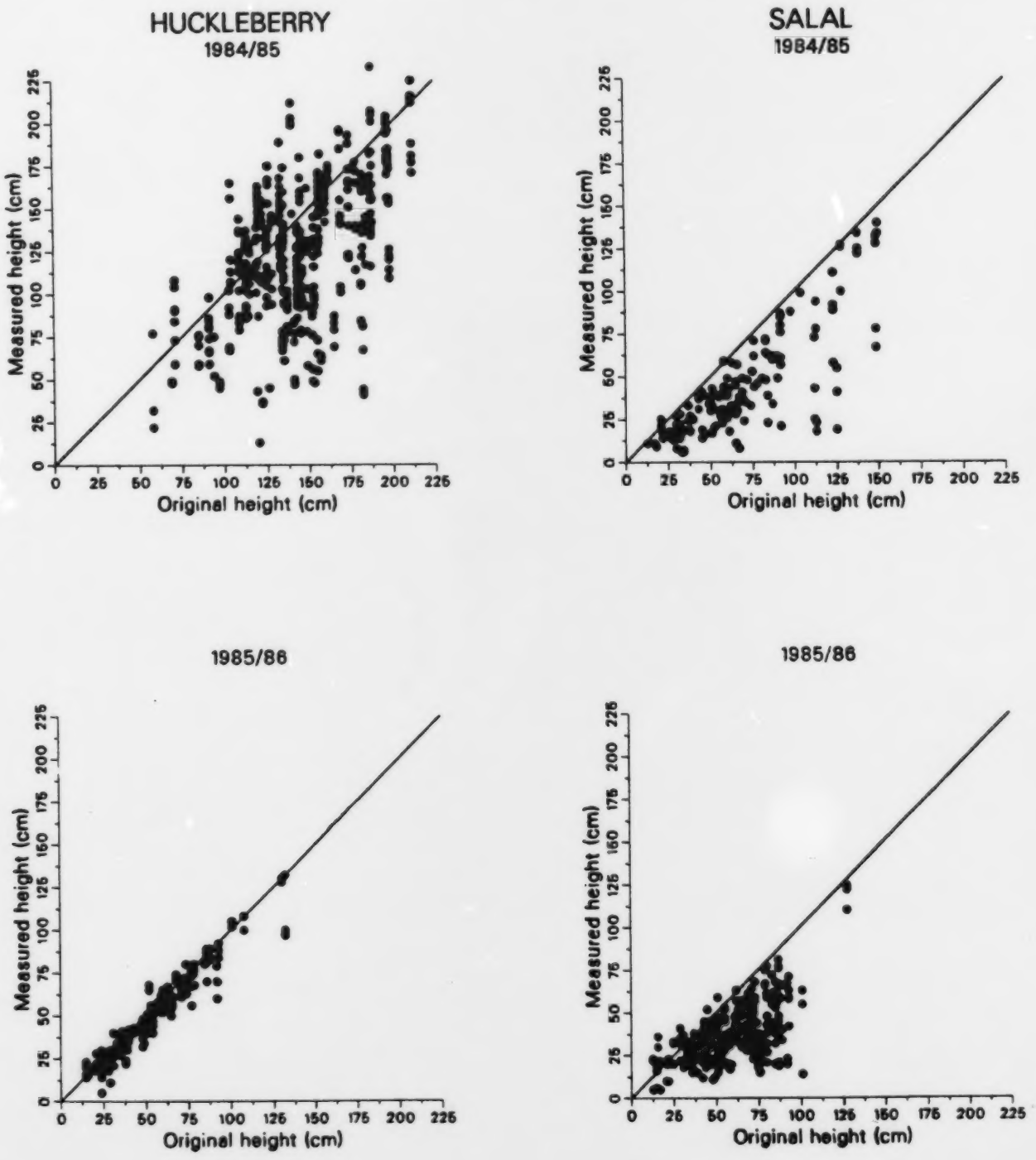

Figure 2. Plant height displacement by snow of huckleberry (*Vaccinium* spp.) and salal (*Gaultheria shallon*) during 1984/85 (data from Gauld 1985) and 1985/86 winters (line shows 1:1 relationship).

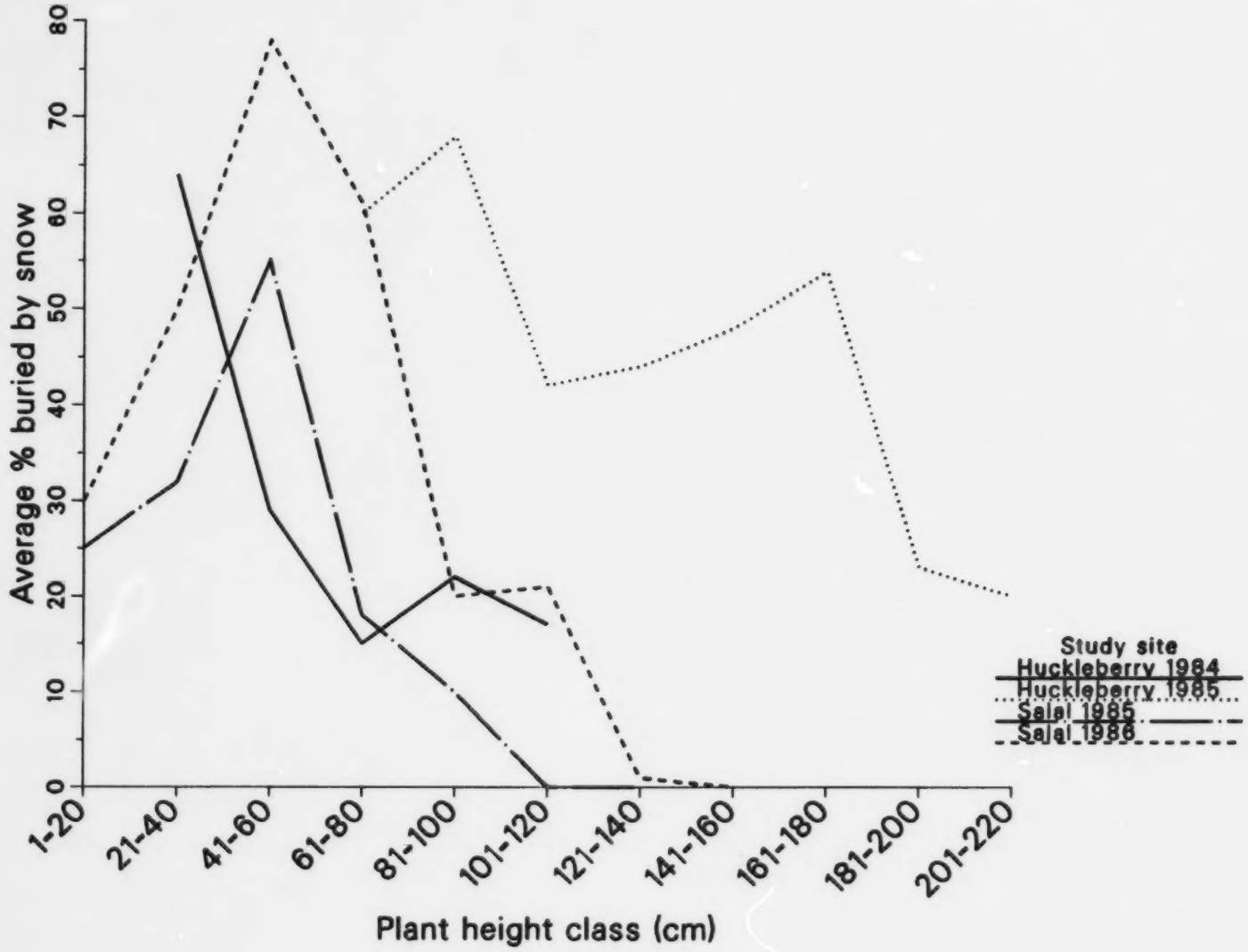

Figure 3. The average percentage of plants taller than snow depth that were buried in huckleberry (*Vaccinium* spp.) and salal (*Gaultheria shallon*) sites (compiled from Harestad and Bunnell 1984; Gauld 1985; Hovey and Rahme, unpubl. data).

Table 3. Proportion of 1985 huckleberry (*Vaccinium* spp.) plants completely buried by snow (data from Gauld 1985)

Mean snow depth (cm)	Plant height class (cm)								
	41–60	61–80	81–100	101–120	121–140	141–160	161–180	181–200	201–220
	n=3[a]	n=6	n=8	n=17	n=19	n=27	n=9	n=9	n=2
66.9	0.66	0.83	0.75	0.25	0.32	0.44	0.44	0.22	1.00
57.9	0.66	0.83	0.63	0.14	0.32	0.33	0.44	0.11	1.00
46.2	0.66	0.66	0.38	0.14	0.16	0.30	0.44	0.00	0.00
41.6	0.50[b]	0.66	0.38	0.14	0.16	0.30	0.44	0.00	0.00
53.5	0.50	0.66	0.38	0.14	0.22	0.33	0.44	0.00	0.00
64.1	0.50	0.83	0.63	0.35	0.22	0.42	0.56	0.22	0.00
75.2	0.50	0.83	0.88	0.64	0.61	0.52	0.66	0.44	0.00
77.1	0.50	1.00	1.00	0.79	0.78	0.63	0.66	0.44	0.00
70.9	0.50	1.00	1.00	0.79	0.78	0.66	0.66	0.44	0.00
54.3	0.50	1.00	0.75	0.71	0.71	0.42	0.66	0.44	0.00

[a]The sample sizes used to derive these proportions are extremely small; the results should be accepted with caution.

[b]A plant in this height class lost a tag; all subsequent proportions are based on n-1 samples.

Table 4. Proportion of 1985 salal (*Gaultheria shallon*) plants completely buried by snow (data from Gauld 1985)

Mean snow depth (cm)	Plant height class (cm) 1-20 n=3[a,b]	21-40 n=20	41-60 n=21	61-80 n=17	81-100 n=8	101-120 n=4	121-140 n=4	141-160 n=2
3.4	0.66	0.45	0.48	0.59	0.00	0.00	0.00	0.00
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.8	1.00	0.75	0.48	0.76	0.38	0.33	0.00	0.00
15.0	1.00	0.95	1.00	1.00	0.50	0.66	0.25	0.00
0.3	0.66	0.32	0.10	0.06	0.13	0.00	0.00	0.00
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a]The sample sizes used to derive these proportions are extremely small; the results should be accepted with caution.

[b]Due to an "oversight", Gauld was unable to measure 21 of his salal plants (Gauld 1985). The sample sizes reported in the table refer to the 79 plants he did measure.

Table 5. Proportion of 1986 huckleberry (*Vaccinium* spp.) plants completely buried by snow

Mean snow depth (cm)	Plant height class (cm) 1-20 n=4[a]	21-40 n=39	41-60 n=27	61-80 n=19	81-100 n=7	101-120 n=2	121-140 n=2
1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.1	0.09	0.75	0.15	0.00	0.00	0.00	0.00
19.0	0.11	0.75	0.21	0.00	0.00	0.00	0.00

[a]The sample sizes used to derive these proportions are extremely small; the results should be accepted with caution.

Table 6. Proportion of 1986 salal (*Gaultheria shallon*) plants completely buried by snow

Mean snow depth (cm)	Plant height class (cm) 1-20 n=4[a]	21-40 n=14	41-60 n=33	61-80 n=30	81-100 n=17	101-120 n=1	121-140 n=1
12.5	0.50	0.36	0.42	0.30	0.12	0.00	0.00
28.3	1.00	0.79	0.61	0.10	0.06	0.00	0.00
27.1	1.00	0.93	0.64	0.13	0.12	0.00	0.00

[a]The sample sizes used to derive these proportions are extremely small; the results should be accepted with caution.

able variation exists (Figure 4[4]). Although the effect of these two factors could be estimated by logistic and multiple regressions, sparseness of the available data prevented reliable use of these techniques.

3 RESEARCH RECOMMENDATIONS

The preceding studies were unable to quantify the factors affecting the shrub burial process adequately, because of either lack of snow (e.g., Harestad and Bunnell 1984; Hovey and Rahme, unpubl. data) or design errors (e.g., Gauld 1985). The following research design would provide the information necessary to satisfy the noted objectives. The design primarily involves multiple and logistic regression models predicting either the amount of plant remaining above the snow ($\hat{Y}$) (multiple regression) or the probability of plant burial by snow ($E(\frac{f}{n})$) (logistic regression) as a function of snow depth (SD), pre-winter plant height (PH), mean crown completeness (MCC) (*sensu* Bunnell *et al.* 1985), and plant flexibility index (PFI). Although all of the studies discussed in this paper occurred on level terrain, that site characteristic may not always be available or desirable (deer winter ranges can occur on steep slopes [see Nyberg *et al.* 1986]). Because the snowpack can slide down the slope (snow creep) and affect the processes of shrub burial, slope should also be measured and treated as a variable in the regression models in those study areas where the ground is not level.

Formally, the proposed research design is not experimental, it is *ex-post-facto*. That is, the independent variables are not manipulated and randomly assigned to experimental units. Given the economic and biological infeasibility of a strict experimental design, this technicality will be ignored. Data for the proposed design would be collected following the methods of Harestad and Bunnell (1984) and the additional methods of Hovey and Rahme (unpubl. data) (i.e., staking plants and recording extra snow depth measurements). To quantify the effects of the changing snowpack, sampling sites on a regular (weekly) basis is recommended.

The multiple and logistic regression models would be composed, respectively, as follows:

$$\hat{Y} = b_0 + b_1(SD) + b_2(PH) + b_3(MCC) + b_4(PFI) \quad (1)$$

where

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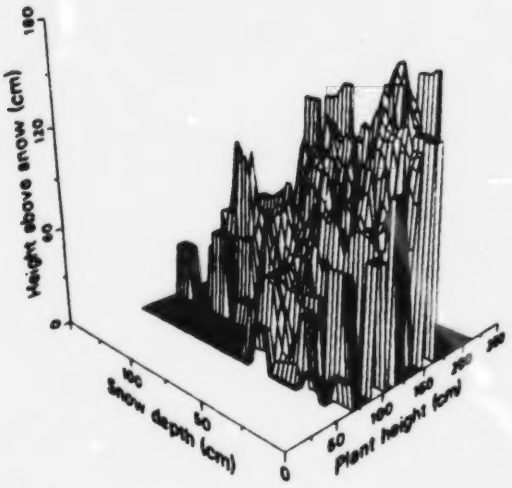
[4]Harestad and Bunnell (1984) and Hovey and Rahme (unpubl. data) data sets were not sufficient to produce similar graphs.

Huckleberry



Salal

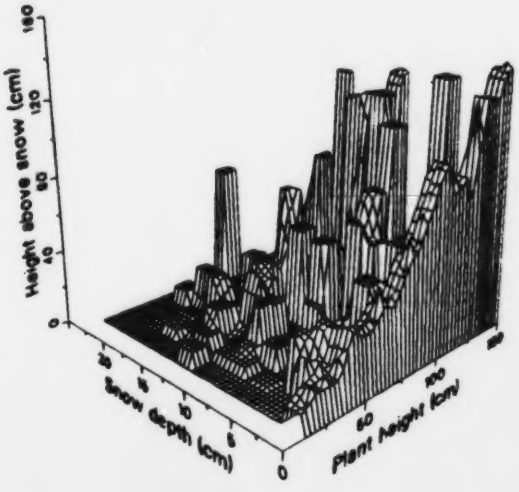


Figure 4. The effect of pre-winter tag height (cm) and snow depth (cm) on the amount of plant remaining above snow (cm) for huckleberry (*Vaccinium* spp.) and salal (*Gaultheria shallon*) during 1984/85 winter (data from Gauld 1985).

b_i = regression coefficient for the i^{th} term, and

$$E(\frac{f}{n}) = e^{(U)} / [1 + e^{(U)}] \quad (2)$$

where $(E(\frac{f}{n}))$ is the predicted proportion of f plants buried for n plants measured and U is a linear function of the independent variables and their interactions (*sensu* Cox 1970).

For the proposed research design, the use of logistic regression is suggested because it accommodates the mixed use of categorical (e.g., MCC) and continuous (e.g., SD, PH) independent factors; thus, it may provide more statistical power than other analytic techniques for binomial data (e.g., log-linear multiway contingency table analysis, binomial analysis of variance) (M. Grieg, pers. comm., Senior Analyst, Computing Centre, Univ. B.C., Vancouver, B.C.).

The inclusion of snow depth and original plant height in the above regression models is obvious; the justification for the inclusion of the other two independent factors follows. The forest canopy affects snow deposition on the ground by intercepting snow (Harestad and Bunnell 1981). It also affects snow depth by influencing snow melt rates (Bunnell *et al.* 1985). These processes of snow accumulation and ablation are, in turn, important factors affecting the dynamics of shrub burial (Bunnell and Jones 1984).

Besides its effect on snow depth, the canopy may also alter shrub burial by influencing the growth form of understory vegetation. Vales (1986) found a significant relationship between MCC and the ratio between the reposed and stretched heights of salal (i.e., PFI). In general, salal plants growing under closed canopies were found to be taller and more flexible than those growing under open canopies. Flexibility influences plant susceptibility to displacement by snow.

Several methods are available for measuring crown closure above a sampling point (e.g., visual estimates, photographic techniques, and spherical densiometer); of these, the moosehorn provides the most precise and economically efficient estimates (Vales and Bunnell 1985). Understory plant growth, however, is not well correlated with single point estimates of crown closure. Several moosehorn measurements are required because plants are also affected by overstory conditions adjacent to their location. D.J. Vales (pers. comm., Dep. of Forestry, Univ. B.C., Vancouver, B.C.) termed the collective action of these overstory conditions the "zone of influence" (ZI). Because the canopy can affect snow deposition and melt rates, as well as understory plant density, cover, and biomass, it is likely that plant height, plant growth form, and, consequently, the shrub

burial process will also be affected by this zone. Vales (pers. comm.) developed a unique technique to estimate ZI and its effect on salal cover and biomass. In his method, plot size is a function of the height to the base of the canopy's live crown (HBLC). With the use of a clinometer, HBLC is determined for the tree closest to plot centre; then, with a 50° projection angle, the plot radius (R) is calculated as:

$$R = HBLC \cdot \tan(50^\circ/2) \quad (3)$$

MCC, which indexes ZI for a 1-m² subplot of understory vegetation located at plot centre, is calculated by averaging 20 moosehorn readings taken from 20 points systematically located throughout the plot. The distance between each point (D) is determined by using the angle subtended by the moosehorn (≈10.2°) and the equation:

$$D = HBLC \cdot \tan(10.2^\circ/2) \quad (4)$$

Because the number of points remains the same (i.e., 20), but D becomes smaller, Vales' method samples plots with low live crowns more intensively (per unit area) than it does those with high crowns. Vales (pers. comm.) suspected that this sampling technique will produce relatively precise overstory-understory relationships for salal in immature forests. An advantage of using his technique is that it may facilitate comparison of results from future shrub burial projects with other overstory-understory relationships (e.g., MCC and salal height distribution) developed by Vales.

As an alternative, a simpler approach to estimating MCC would be to sample 25 systematically located points (e.g., 2 m apart) in a 64 m² (8 x 8 m) quadrat that encompasses the plot centre. Such an approach should be less time consuming than the recommended one, but it may not be as accurate.

Unlike the measurements of MCC, indexing the flexibility of each plant is straightforward. PFI can be estimated as the ratio of reposed height (i.e., PH) divided by stretched height (i.e., maximum height) (*sensu* Vales 1986). In addition to this index, measuring each plant's basal diameter is also recommend, as it is likely that plant flexibility is related to stem thickness as well as to the angle of repose.

Determination of MCC and PFI could occur either before winter or immediately after it. The choice of method depends on the potential tradeoff between site disturbance (before winter) and canopy and understory plant changes due to wind and snow breakage (after winter). Although final evaluation of this tradeoff should be left to the discretion of the researcher, site disturbance probably has greater potential as a source of error; thus, MCC and PFI should be measured after winter. Another advantage of determining MCC and PFI after winter is that it accommodates the possibility of

justifiably ignoring MCC and PFI in the research design. For example, once the data have been collected, preliminary stepwise multiple and logistic regressions using just SD and PH may produce acceptable R^2's and standard errors thus eliminating the need to sample MCC and PFI. Some researchers, however, may wish to measure MCC to allow shrub burial processes to be integrated with other aspects of deer habitat that relate to canopy closure.

Because snow burial of shrubs has been shown to vary among habitats and snow regimes (Jones 1975; Harestad 1979; Rochelle 1980), repeating the proposed research design in at least three winter ranges is advisable. Estimation of between-habitat variability will provide a means of assessing the applicability of regression equations to other winter ranges. For the multiple regression model, the significance of the variation due to habitat can be determined by covariance analysis testing differences in the regression surfaces developed for each area. In the logistic regression model, the habitat effect would be treated as part of the linear model (i.e., U).

Proper estimation of the factors affecting the dynamics of shrub burial is essential to the objective of accurately estimating forage availability and carrying capacity on ungulate winter ranges. The preceding research design and its proposed analyses are offered as the first step to accomplishing that objective.

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